Upper Meter Processes: Short Wind Waves, Surface Flow, and Micro-Turbulence

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LONG-TERM GOAL

The primary goal of this project is to advance the knowledge of small-scale air-sea interaction processes at the ocean surface, focussing on the dynamics of short waves, the surface flow field and the micro-turbulence. Since ground truth on the small-scale shape of the sea surface and the processes forming it is still widely missing, a better understanding of the physics of these upper meter processes is of utmost importance for the study of electromagnetic backscatter from the sea surface.

OBJECTIVES

The scientific objective of this research project includes the development and use of novel experimental methods based on imaging optical techniques to measure both short wind waves and the turbulence and flow field at the ocean interface. The area extended data resulting from these instruments are combined with meteorological ground truth to obtain a better insight into the dynamics of the interaction between short wind waves and the turbulent drift layer at the ocean surface as a function of wind stress, surface films, surface currents, and swell.

APPROACH

Our experimental approach is centered around a drifting buoy that carries an improved imaging wave slope system (ISG) and an infrared imaging system for the simultaneous measurement of the wave slope and microscale temperature fluctuations within the same foot print. Image sequences from the infrared system are evaluated with image sequence processing techniques to determine the flow field at the surface of the ocean.

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WORK COMPLETED

1. After the computer system failure of the wave buoy during the North Atlantic CoOP cruise in June/July 1997 a complete redesign of the computer and control system was required. This has been completed now and the whole system is currently been tested in the Scripps Hydrolab. Because of the importance of high slopes for radar backscatter the wave imaging system has carefully be checked and calibrated for high wave slopes. It turned out that the system is capable of measurements of slopes up to 1.2 (50 degree) over the whole image sector - more than we initially expected.

2. Image sequence processing algorithms have been developed to determine the surface flow field from infrared imagery. With this development it is possible to measure the surface flow field simultaneously to the phase speed of the short wind waves (obtained from the wave slope images) and thus to determine phase speeds of the waves relative to the surface flow field. The image processing algorithms are exact enough to allow also for the determination of derivatives of the flow field such as the divergence and rotation of the flow field (Jaehne et al., 1998; Haussecker and Jaehne 1998)

3. Our large base of laboratory data, which has proven essential for the comparison with field data, has been extended with additional measurements from the Wallops wind/wave flume.

4. A new technique has been developed to analyze wave slope images in the space/wave number domain in order to determine the local wave numbers and the direction of the waves. This new technique is based on a scale space decomposition of the wave images including a decomposition in 6 directional components using steerable filters (Carstens, 1998). Since such filters can be steered in any direction, it is possible to generate a four-dimensional data structure that determines the distribution of waves in wave number and direction for each point in the image. With a nonlinear regression technique, up to three superimposed wave components can be detected simultaneously. This novel technique gives a spatially resolved distribution of wave numbers, including the individual amplitude of the waves. Thus it gives much more insight than conventional Fourier transform techniques and power spectra.

RESULTS

The comparison of the wave number spectra of short wind waves from the lab and the field show large scatter of the spectral densities at low wind speeds. This can be attributed to the effect of surface films and background wave conditions. For higher wind speeds the dependence of the spectral density on the friction velocity is found to vary with the wave number from linear for short gravity waves to almost cubic for capillary waves.

Other investigators (Hara et al. (1994) and Hwang et al. (1996)) observed significantly higher spectral densities at low wind speeds than our laboratory data (Jaehne and Riemer, 1990) from the Delft wind wave flume at 100 m fetch. As one possible explanation they offered the fluctuating component of the wind field, which is high in the field but low in the laboratory. Meanwhile, however, we have accumulated much more detailed data including measurements form the Delft, Marseille, Heidelberg, and Wallops facilities. The data show that the 1988 Delft data have the lowest spectral densities.

Especially the spectral densities in the Heidelberg facility with unlimited fetch, are a factor of 2-4 higher at low wind speeds and therefore similar to the field data. This suggests another explanation for the higher spectral densities of short waves at low wind speed under oceanic conditions. Since the pioneering experiments of Cox (1958), it is known that steep short gravity waves generate parasitic capillary waves without applying wind. In the field, where additional sources exist for the generation of short gravity waves, it is natural that parasitic capillary waves should be produced more frequently.

The novel technique to analyze waves slope images as described in section WORK COMPLETED 4 has been used to compute distributions of the slope amplitude as a function of the wave number. In contrast, the Fourier transform essential gives only the mean value of this distribution. These "amplitude resolved" spectra show very interesting results. At low wind speeds, the spectral density of capillary waves is much lower than that of short gravity waves. However, the mean steepness of the capillary waves is still higher. The capillary waves just occupy a much smaller area. At high wind speeds, when the saturation range of the capillary waves is higher than that of short gravity waves, the slope distribution of capillary waves and short gravity waves is similar, except for a long tail towards steeper slopes in the distribution for capillary waves.

IMPACT/APPLICATION

The data acquired during MBL ARI 1995, during the CoOP cruise 1997, and future measurements from the SIO Marine Observatory will finally allow for a systematic study of the parameters influencing the wave number spectra of short wind waves. As demonstrated by the recent results, the quantitative comparisons with our detailed measurements of wave number spectra in laboratory facilities under controlled conditions will be an invaluable asset for the understanding of the wave number spectra measured at sea.

The new wave imaging buoy permits the study of the interaction of surface turbulence and surface waves, by using the wave slope imaging technique in combination with the infrared imaging of the water surface. It is also suitable to measure the modulation of short waves by long waves.

TRANSITIONS

The IR surface turbulence imaging technique is now being used by K. Melville (Scripps Institution of Oceanography) in an NSF project on generation and evolution of Langmuir circulation in the laboratory and by A. Jessup (APL, University of Washington, Seattle) to study the influence of microscale wave breaking on gas transfer. In the last year we have assisted even more researchers, devices including K. Melville (Scripps Institution Oceanography), N. E. Huang (NASA/Goddard Space Flight Center) and S. Long (NASA/Wallops Flight Facility), and taught them how to use the wave slope imaging technique. More recently, M. Donelan (University Florida, Miami) has inquired about the use of the technique. Given the significant number of researchers that are now using the observational techniques developed by our research group, it is fair to say that our research, sponsored by the ONR in the last eight years, has triggered a new quality in the experimental investigation of small-scale air-sea interaction processes.

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